Population differences in cork oak for growth and survival under contrasting environmental conditions

Teresa Sampaio[1], João Costa e Silva[1], Leopoldo Sanchez[2], M. Sameiro Patrício[3], M. Helena Almeida[1]*

1 - Centro de Estudos Florestais, Instituto Superior de Agronomia, Universidade de Lisboa, Tapada da Ajuda,1349-017 Lisboa, Portugal

2 - INRA Centre Val de Loire, Unité Amélioration Genétique et Physiologie Forestiéres, 2163 Avenue de la Pomme de Pin, BP 20619 Ardon, 45166 Olivet Codex, France

3 - Centro de Investigação de Montanha (CIMO), ESA - Instituto Politécnico de Bragança, Campus de Stª Apolónia, Apartado 1172, 5301-854 Bragança, Portugal

Introduction

A key issue when pursuing reforestation is to know whether local provenances will still show good survival and growth under current changing environmental conditions.

Cork oak (*Quercus suber*) is a species with high economic and ecological value, with a wide distribution across the Mediterranean basin. In Portugal alone, the species accounts for around 50% of the world's cork production.

An international series of cork oak provenance trials has been established in 1998 to assess levels and patterns of variation between provenances, as well as the magnitude of genetic variation within provenances. Thirty-five cork oak provenances, covering the entire range of the species' natural distribution are represented in these multi-environment trials (Varela, 2000).

Results from trials of this series that were established in Portugal and Spain indicated significant provenance variances for survival, growth and adaptive traits (e.g. Ramirez-Valiente et al., 2011; Sampaio et al., 2016), and suggested that cork oak seed origin must be considered in reforestation practices of the species

Fig.1 Monte da Fava cork oak provenance trial.

Aims

- **Assess the (co)variation of cork oak provenance effects for growth and survival traits within and across environmentally contrasting sites.**
- **Evaluate the impact of classifying provenances into groups of climate similarity on the magnitude and significance of (co)variance estimates obtained for provenance effects.**

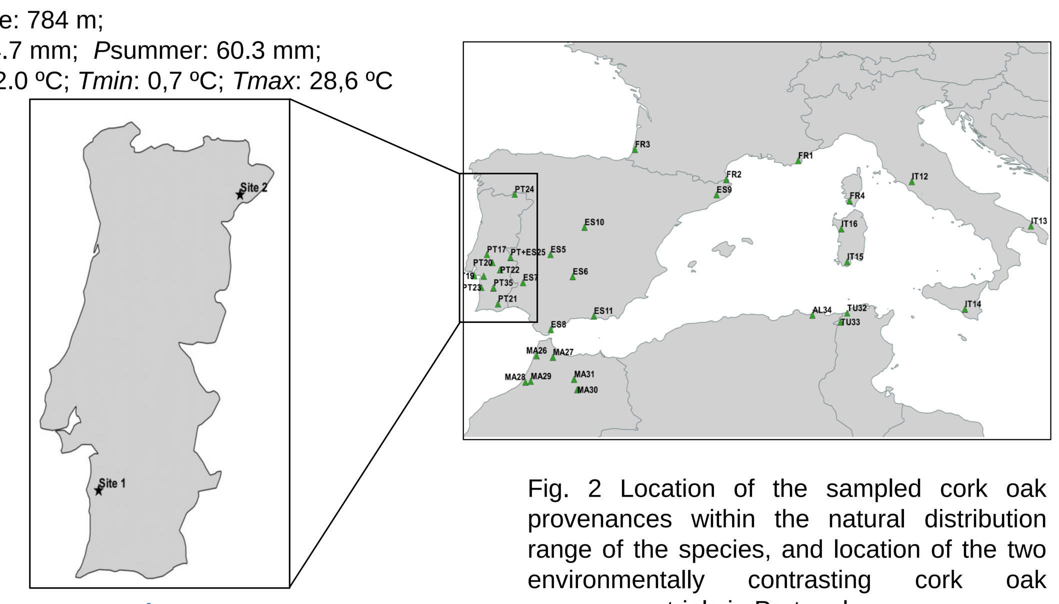
Materials and methods

Plant material and field trials

- Two cork oak provenance field trials established under different environmental conditions in Portugal (Fig. 2).
- 35 and 34 cork oak provenances, covering the entire natural distribution of the species, are tested at Monte da Fava (site 1) and Quinta da Nogueira (site 2), respectively.
- Randomized complete block design with 30 blocks, and 4 plants per provenance in each block, planted at 6×6m spacing.

Site 2 - Quinta da Nogueira

Altitude: 784 m;
P: 554.7 mm; *Psummer*: 60.3 mm;
Tm: 12.0 ºC; *Tmin*: 0,7 ºC; *Tmax*: 28,6 ºC



Site 1 - Monte da Fava

Altitude: 79 m;
P: 556,6 mm; *Psummer*: 19,4 mm;
Tm: 15,8 ºC; *Tmin*: 4,3 ºC; *Tmax*: 31,3 ºC

Fig. 2 Location of the sampled cork oak provenances within the natural distribution range of the species, and location of the two environmentally contrasting cork oak provenance trials in Portugal.

Measurements

- Total height (HT) and above-ground diameter at 10 cm (D) to assess growth, and mortality (MORT) to assess tree survival, at age 14 years after planting.

Data analysis

a) We used a multi-site linear mixed model for growth traits and a multi-site generalized linear mixed model, considering a Bernoulli distribution and a logit link function, for MORT.

Site was considered as fixed effect. Heterogeneous variances between sites were included for block, provenance and residual effects (i.e. for random effects) and an across-site covariance was fitted for provenance effects.

Fixed effects were tested using a Wald-type F-test. One-sided likelihood ratio test (LRT) were used to test the significance of the variance estimates for provenance and block effects, and to test across-site correlation estimates for provenance effects

b) A bivariate linear mixed model was performed to estimate trait correlations for provenance effects at each trial.

c) Multivariate analyses (Principal component analysis and Cluster analysis), using independent climate variables from the site of provenance origin (summer precipitation (SP), summer mean maximum temperature (SMMT) and winter mean minimum temperature (WMMT)) were performed to group provenances according to the degree of climate similarity (called "climate group"). This was used to create a "climate group" factor which was included as a fixed effects term in the linear mixed model described in a).

The analyses were carried out with ASReml and R softwares.

Results

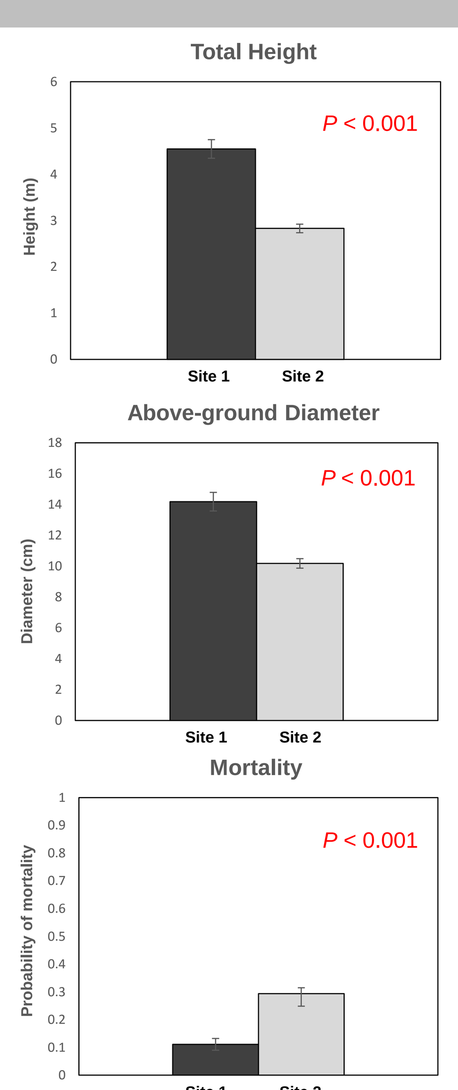


Fig. 3 Estimated generalized least- square means (LSM) at site 1 and site 2 for HT, D and MORT, and empirical Bayes estimates (EBE) for MORT. For MORT, the LSM represents the expected probabilities of mortality.

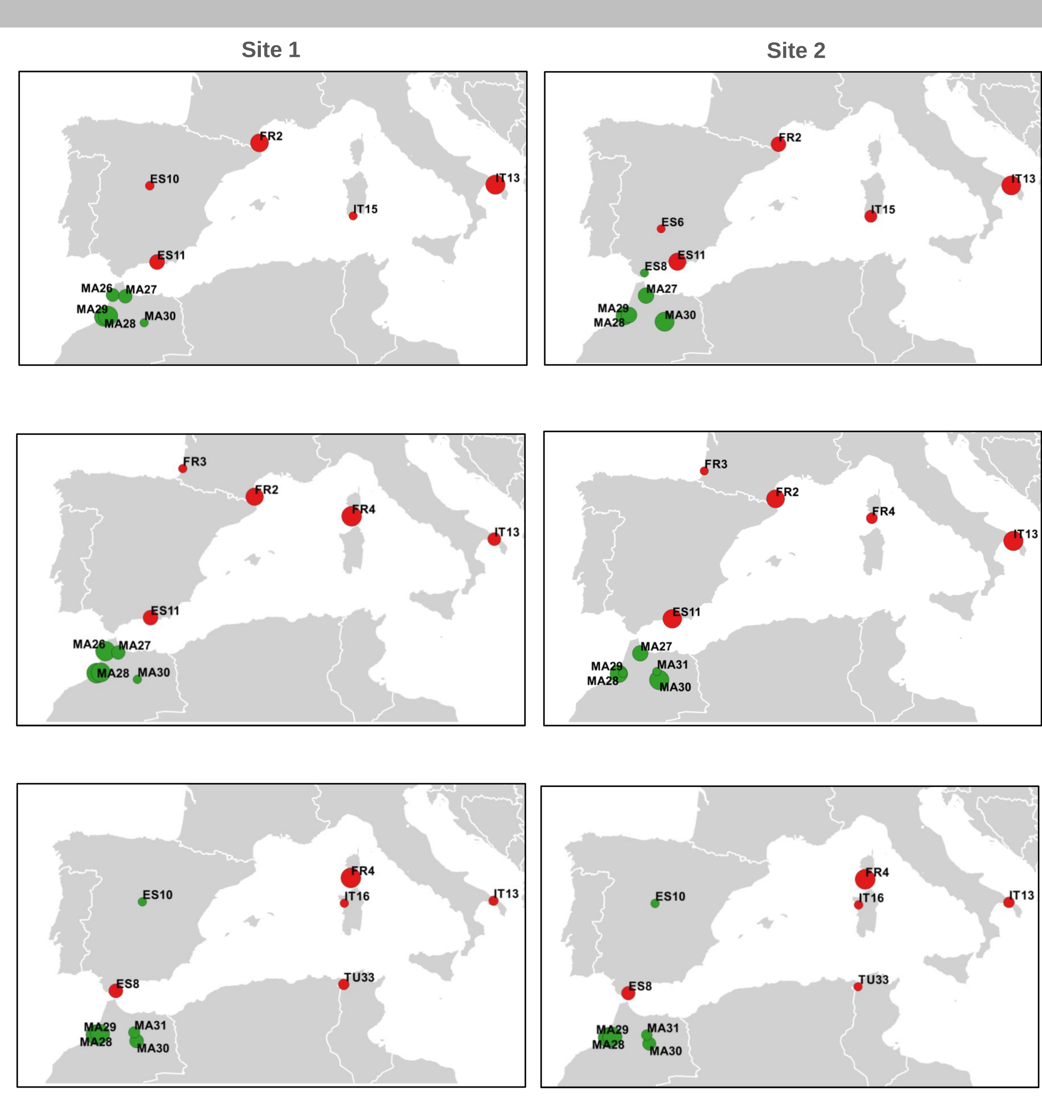


Fig. 4 Provenance rankings based on Empirical best linear unbiased estimates (EBLUPs) of provenance effects for HT and D, and empirical Bayes estimates (EBE) for MORT. Only the 5 provenances with the highest (green symbols) and the lowest performances (red symbols) are shown. Symbol size represents the magnitude of the EBLUPs or EBE values.

Across-site correlation for provenance effects (± standard error)

0.82 (±0,11) (*P*=0.01)

0.77 (±0,13) (*P*<0.01)

1,05 (±0,26)

Table 1. Provenance correlation (± standard error) between the studied traits (HT, D and MORT) at site 1 and site 2.

	Site 1	Site 2
HT - D	0.94 (0.02)	0.96 (0,02)
MMORT - HT	-0.40 (0.24)	-0.43 (0.29)
MORT -D	-0.42 (0.24)	-0.27 (0.30)

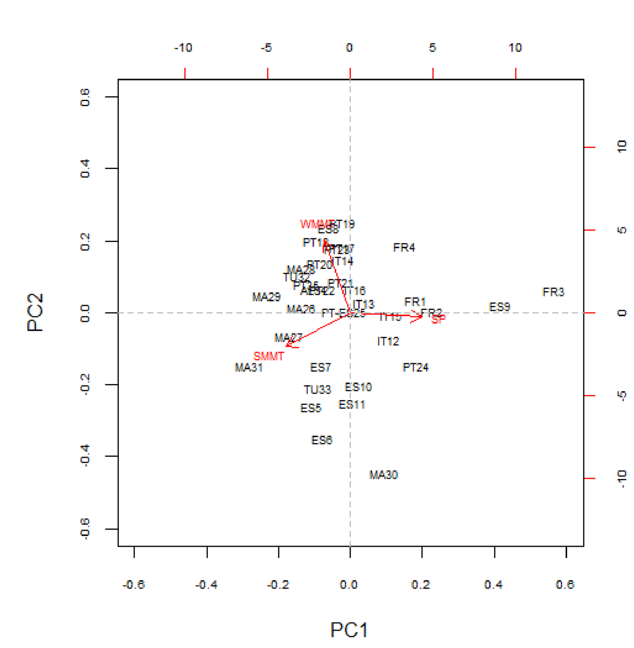


Fig. 5 PCA biplot of the climate variables for the 35 provenances; vectors (in red) represent climate variables (SP, SMMT and WMMT) and text represent provenance codes.

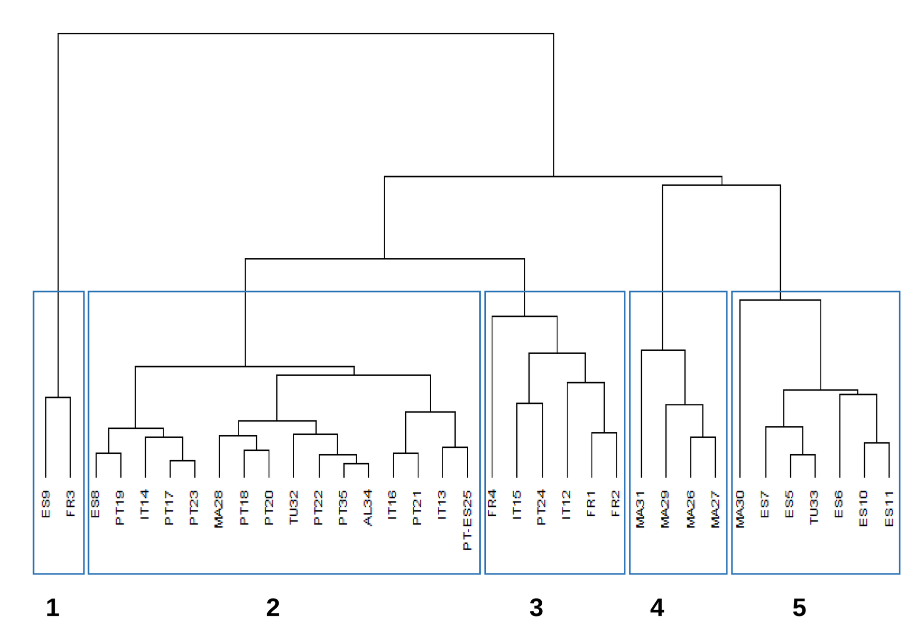


Fig. 6 Dendrogram based on an agglomerative hierarchical method using the furthest neighbor metric. Five clusters separated provenances in the following climate groups: (1) Mediterranean with warm and very wet summers; (2) Mediterranean with mild winters and warm-dry summers; (3) Mediterranean with mildly-wet and warm summers; (4) Mediterranean with hot-dry summers; (5) Mediterranean with cold winters and hot summers.

Conclusions

- Under contrasting field environmental conditions, total height, diameter and survival differed significantly across sites at the mean level. The combined effect of higher altitude and lower winter mean temperatures at site 2 resulted in lower provenance growth and higher mortality.
- The geographic origin influenced cork oak performance for survival and growth (highly significant provenance variance estimates). Provenances originating from Morocco had the highest survival and the fastest growth at both sites, and thus performed better than local ones. This suggests that southern geographic sources of seed are better adapted to current changing environmental conditions than local provenances, confirming the need to consider seed origin in future reforestation with cork oak in Portugal. This also suggests a possibility of anticipating (in a few years) the first cork stripping and the onset of economic returns with Moroccan provenances.
- Significant G×E interaction was detected for total height and diameter, indicating provenance variation in phenotypic plasticity for growth. The ability of provenances to respond to environmental change will provide an opportunity to develop reforestation strategies for adapting cork oak forests to changing climatic conditions.
- Although modelling a "climate group" term led to a significant interaction effect with site and decreased the magnitudes of site provenance variances, the fact that the latter estimates still remained statistically significant indicated that factors other than climate (e.g. soil, nutrient content, etc) are likely to be important to explain provenance variation, as well as contribute to local adaptation, for growth traits.

References:

- Ramírez-Valiente J.A., Valladares F., Huertas A.D., Granados S., Aranda I., 2011. Factors affecting cork oak growth under dry conditions: local adaptation and contrasting additive genetic variance within populations. Tree Genet. Genomes 27 (2), 285-295.
- Sampaio T., Branco M., Guichoux E., Petit R.J., Pereira J.S., Varela M.C. Almeida M.H., 2016. Does the geography of cork oak origin influence budburst and leaf pest damage? Forest Ecol. Manag., 373, 33-43.
- Varela M.C., 2000. European network for the evaluation of genetic resources of cork oak for appropriate use in breeding and gene conservation strategies. Handbook, Lisboa.

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